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MEASUREMENTS OF THE COMPONENT OF REACTION OF THE CUTTS COMPENSATOR AND OF THE BROWNING FLASH HIDER ALONG THE RADIAL AXIS OF ASYMMETRY

by

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MEASUREMENTS OF THE COMPONENT OF REACTION OF THE CUTTS COMPENSATOR AND OF THE BROWNING FLASH HIDER ALONG THE RADIAL AXIS OF ASYMMETRY.

O.P. 4846.

Introduction: It is a commonly known fa that the muzzles of the machine guns and automatic rifles tend to rise during a burst of fire. In an attempt to correct this rise of the muzzle, the Cutts Compensator and the Browning Flash Hider have been made to produce a downward reaction on the muzzle. It was desired to obtain measurements of this downward reaction of the Cutts Compensator and the Browning Flash Hider.

Apparatus: The ballistic pendulum which was used in the measurement of the recoil velocities of various machine guns and rifles in connection with O.P. 2846 was modified slightly to act as a bifilar-pendulum. The Cutts Compensator and Browning Flash Hider were so oriented that their component of reaction took place in a horizontal plane and produced an oscillation of the bifilar-pendulum.

A stylus was attached to both the muzzle and breech end of the gun and thus a two-dimensional record of the motion of both the muzzle and breech was obtained. The traces of the two styluses were recorded photographically and rulers were placed in the field so as to give the proper scale.

Theory: Each of the styluses produced an approximately linear trace* which made an angle with the horizontal projection of the initial direction of the axis of the bore.

*The first part of the trace could be taken as linear.

Then let r be the distance measured along the direction of the axis, let z_m be the component of the motion of the muzzle stylus perpendicular to the axis and let z_b be the component of the motion of the breech stylus perpendicular to the axis. (See Figure 1)

Then the velocity of recoil is $\frac{dr}{dt}$, the transverse velocity of the muzzle stylus is $\frac{dz_m}{dt}$ and the transverse velocity of the breech stylus is $\frac{dz_b}{dt}$.

Let the angle which the muzzle trace makes with the initial direction of the horizontal projection of the axis of the bore be λ_m and the corresponding angle for the breech stylus be λ_b. Then, if for the first part of the motion we assume the velocity to be constant, we have if we write V_r for $\frac{dr}{dt}$

$$\frac{dz_m}{dt} = \dot{z}_m = V_r \tan \lambda_m$$

and

$$\frac{dz_b}{dt} = \dot{z}_b = V_r \tan \lambda_b.$$

The initial value V_r to be used in these equations can be computed from the amplitude of the oscillation of the ballistic pendulum. (See "Measurements of Recoil Velocities of Various Machine Guns and Rifles in Connection with O.P. 2846.")

Let θ be the angle which the axis of the bore makes at any time with the initial direction of the axis before firing. Then $\dot{\theta}$ is equal to $\frac{\dot{z}_m - \dot{z}_b}{h}$ where h is the distance between the two styluses.

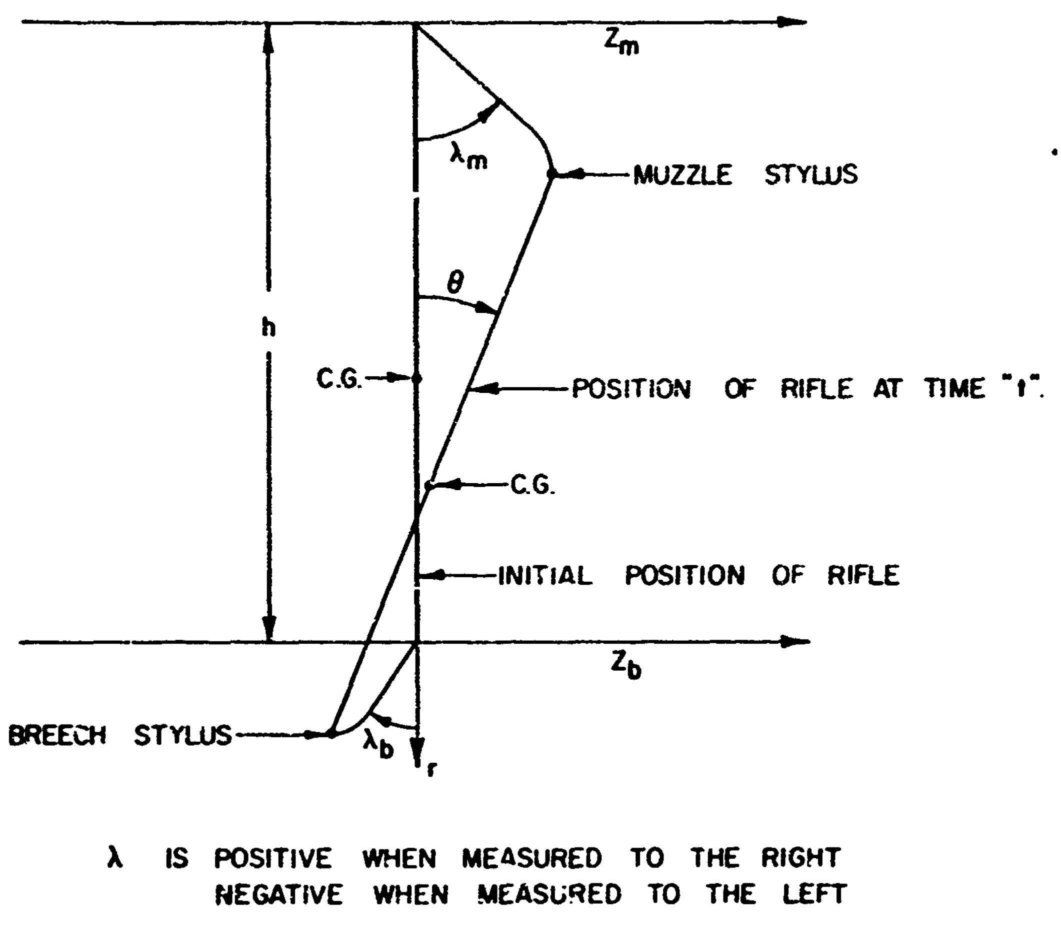

Figure 1.— Showing Coordinates for the Motion of the Bob.

If I is the moment of inertia of apparatus about a vertical axis through the center of gravity, then the impulsive couple* produced by the reaction of the flash hider or the compensator is given by

$$I\,\dot{\theta} \text{ (lbs.ft.}^2\text{/sec.)}$$

If d is the distance from the point of application of the reaction of the flash hider to the center of gravity of the pendulum then the impulse* produced by the reaction is equal to

$$\frac{I\,\dot{\theta}}{d} \text{ (lbs.ft./sec.)}$$

It has been explained how from the trace of the styluses it is possible to determine $\dot{z}_m$ and $\dot{z}_b$ and hence the value of $\dot{\theta}$. Thus if the value of I, the moment of inertia, is known, the value of the impulse $\frac{I\,\dot{\theta}}{d}$ can be computed.

To determine I, the period of oscillation of the bifilar-pendulum may be observed and the value of I may then be computed after one has deduced the equation connecting I and T, the period of the pendulum.

Theory of the Bifilar-Pendulum.

Figure 2 shows the bob BM suspended by the wires LL. The length of the bob is assumed to be k and the distance of the center of gravity of the bob from the breech wire is taken to be p k and the distance of the center of gravity of the bob from the muzzle wire is taken to be q k. Let us assume that the axis of the bob has been displaced by an angle θ from its initial direction. Then the muzzle wire will make an angle ϕ_m and the breech wire will make an angle ϕ_b with the ir initial direction. If the length of each of the two suspending wires is L, then ϕ_m and ϕ_b are expressed in terms of θ by the following equations:

*See page 4a for definition of "Impulse" and "Impulsive Couple".

Definition of "Impulse" and "Impulsive Couple".

Consider a mass, m, moving along the x axis which is acted on by a force F* for a short time.

We have for the motion

$$m \frac{d^2x}{dt^2} = F$$

and

$$m \frac{dx}{dt} = \int_0^{\tau} F\,dt + \text{Constant}$$

or

$$m \frac{dx}{dt}_{t=\tau} - m \frac{dx}{dt}_{t=o} = \int_0^{\tau} F\,dt.$$

If we designate $\int_0^{\tau} F\,dt$ by P, then P is called the "Impulse" and gives the change in momentum due to the application of the force F, during the time interval τ.

Similarly suppose a body of moment of inertia I, is acted upon by a couple M* for a short time τ. If θ is the angle through which the body turns, we have

$$I \frac{d^2\theta}{dt^2} = I \ddot{\theta} = M$$

and

$$I \frac{d\theta}{dt}_{t=\tau} - I \frac{d\theta}{dt}_{t=o} = \int_0^{\tau} M\,dt.$$

$\int_0^{\tau} M\,dt$ is called the "impulsive couple" and is seen to be equal to the change in the moment of momentum, which it produces.

*Neither F nor M are assumed to be constant.

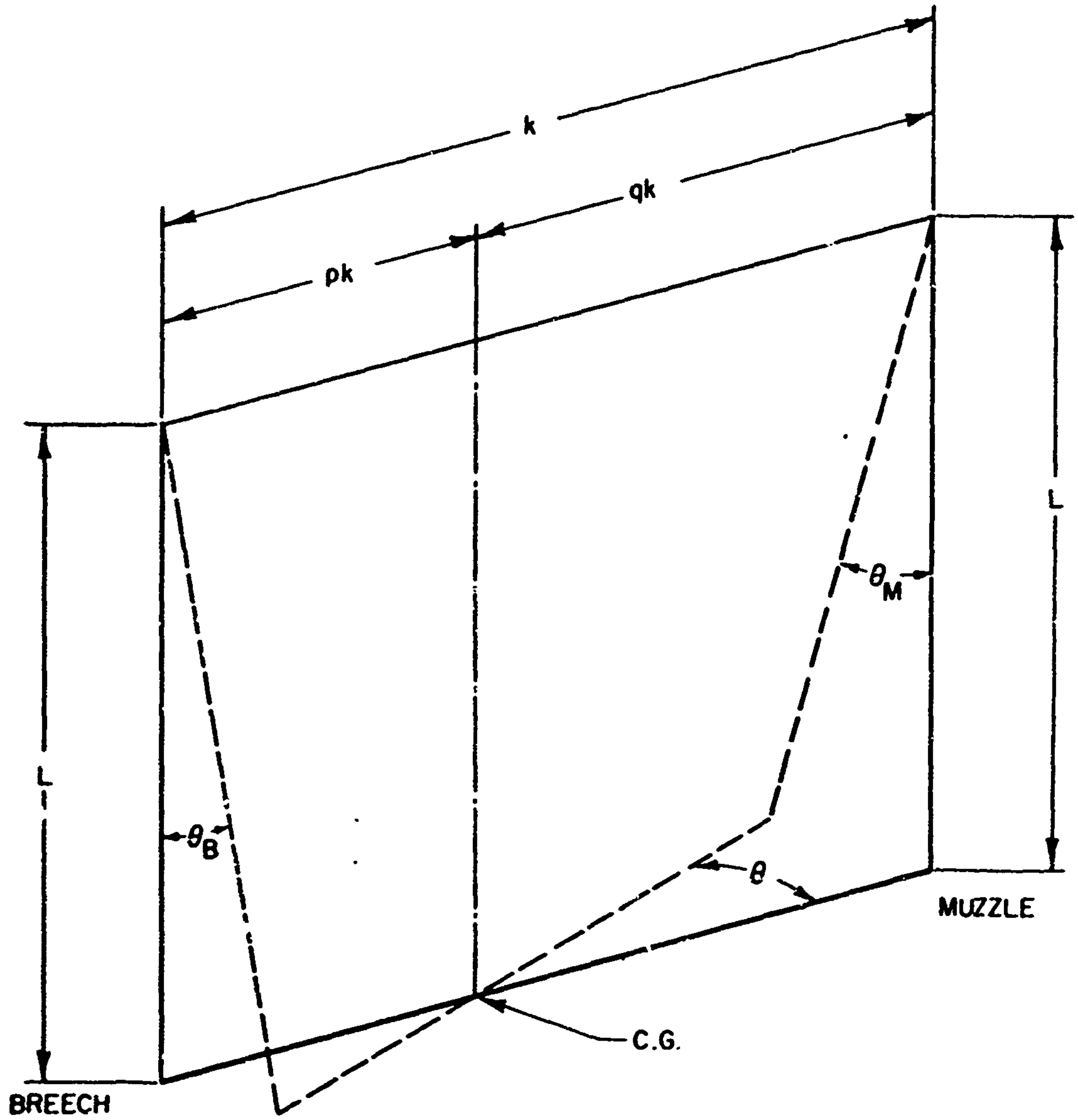

Figure 2 — Showing Coordinates for Motion of Bifilar Pendulum.

$$L\,\phi_b = p\,k\,\theta.$$

$$L\,\phi_m = q\,k\,\theta.$$

Let m be the mass of the bob. Then the downward component of the weight of the bob on the muzzle wire is p m g and the downward component on the breech wire is q m g. If the two wires are displaced from their positions as shown, the couples tending to restore them to their initial position are seen to be p m g sin ϕ_m and q m g sin ϕ_b, if θ is assumed to be small. We then have that the couple tending to cause the bob to turn to its initial position is $(p\,k\,q\,m\,g\,\phi_b + q\,k\,p\,m\,g\,\phi_m)$.*

If we express ϕ_b and ϕ_m in terms of θ, the expression for the restoring couple, M, becomes

$$M = \frac{p\,k\,q\,m\,g\,p\,k\,\theta}{L} + \underline{q\,k\,p\,m\,g\,q\,k\,\theta} =$$

$$= \frac{k^2}{L}\,m\,g\,\theta\,(p^2\,q + q^2\,p).$$

Now, $p + q = 1$.

Hence we have for the equation of motion for the bifilar-pendulum

$$I\,\ddot{\theta} - \frac{k^2}{L}\,m\,g\,p\,q\,\theta = 0.$$

and by comparing this equation with the ordinary one for a simple Harmonic motion, it is seen that I is given by

$$I = \frac{m\,g\,k^2\,p\,o\,T^2}{4\,\pi^2\,L}$$

where T is the period.

*For small oscillations $\sin\phi = \phi$, etc.

Theory of the Rise of the Muzzle.

If the momentum of the projectile and gases is represented by M_r and the distance between the axis of the bore and the middle of the butt is represented by e (See Figure 3), then the impulsive couple due to the discharge of the piece is $M_r e$. Let us assume that if the compensator exerts an impulsive reaction, P*, downwards at the muzzle and if the distance of the point of application of this reaction from the butt is f, then the impulsive couple about the butt due to the reaction of the compensator is seen to be Pf. It is evident that if Pf is equal to $M_r e$, then one will have perfect compensation and there will be no tendency of the muzzle to rise. $(M_r e - Pf)$, we shall call the uncompensated impulsive couple.

Suppose that there were n rounds per second fired from the automatic rifle, then it is evident that the average couple required to prevent the elevation of the muzzle will be

$$n(M_r e - Pf) \quad (\text{lbs.ft.}^2/\text{sec.}^2).$$

The amount of this couple in ft. lbs. is obviously

$$\frac{n(M_r e - Pf)}{g}.$$

Physical Characteristics of Apparatus.

The necessary measurements of the physical characteristics of the apparatus are given in Table I as follows:

*$P = \frac{I\dot{\theta}}{d}$ See Page 4.

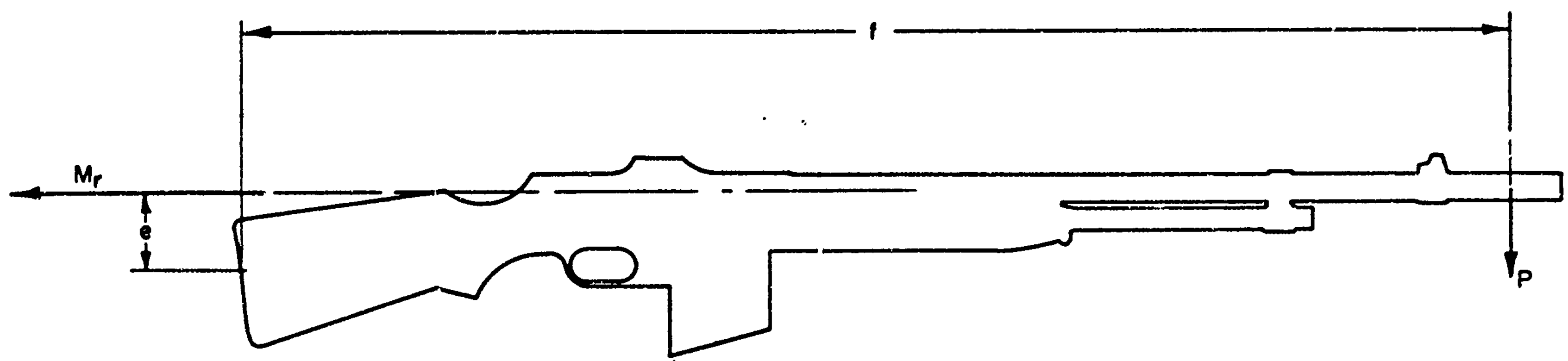

Figure 3.—Showing Certain Dimensions of Browning Machine Rifle.

TABLE I

Mass of bob with compensator	m	34.6 lbs.
Distance between muzzle stylus and breech stylus	h	4.08 ft.
Length of suspension wires	L	6.31 ft.
Distance between the suspension wires	k	3.48 ft.
Positions of the center of gravity with respect to the two wires are given by the quantities (See Figure 2)	(p	.57
	(q	.43
Period of the Bifilar Pendulum	T	1.90 sec.
Distance from c. of g. to muzzle	d	2.2 ft.
Length of rifle from butt to muzzle	f	3.75 ft.
Distance from axis of bore to middle of butt	e	.26 ft.
Moment of inertia	I	48.3 lbs.ft.^{2}

Measurements and Analysis of Results.

The Record of Firings and Measurements is given in Table II. The values of tan λ_m and tan λ_b for each round were obtained from the plots which are attached.

The results of the analysis are given in Table III.

TABLE II

RECORD OF FIRINGS AND MEASUREMENTS

Rd. No.	Attachment	Recoil, r, inches	V_r ft./sec.	$\tan\lambda_m$	$\tan\lambda_b$	$\dot{z}_m$ ft./sec.	$\dot{z}_b$ ft./sec.	REMARKS:
1	Flash Hider	13.96	2.64	-.168	+.105	-.444	+.277	Opening to the right.
2	Flash Hider	13.75	2.60	+.152	-.167	+.395	-.435	Opening to the left.
3	None	13.80	2.61	-.009	-.014	-.023	-.037	
4	Cutts Compensator	9.06	1.72	-.064	+.046	-.110	+.079	Kick to left.
5	Cutts Compensator	9.12	1.72	+.082	-.050	+.141	-.086	Kick to right.

TABLE III

RESULTS OF ANALYSIS

Attachment	I lbs.ft.^{2}	$\dot{\theta}$ * rad/sec.	I$\dot{\theta}$ lbs.ft.^{2}/sec.	P (impulse) lb.ft./sec.	Impulsive Couple about center of butt due to discharge of piece lbs.ft.^{2}/sec.	Impulsive couple about butt due to attachment lbs.ft.^{2}/sec.	Uncompensated impulsive couple lbs.ft.^{2}/sec.
Flash Hider	48	.190	9.2	4.2	24	16	8 **
None	48	.003	.14	.07	--	--	--
Cutts Comp.	48	.051	2.5	1.1	15	4	11 **

*The values of $\dot{\theta}$ are the mean of the values for the two rounds with each attachment.

**If the rate of fire is 10 rounds per second, then the average uncompensated couple for both compensators is about 10 x 10 = 100 lbs.ft.^{2}/sec.^{2}. If this were opposed by the left hand placed two feet from the butt, the hand would have t exert a force of 50 poundals or 1.5 pounds to prevent the rise of the muzzle. Without the compensators, a force of about four pounds would be required.

Discussion of Results.

The precision of the measurements of the reaction of the flash hider was not very great, possibly due to the motion of the pendulum due to the gusty wind. Based on the small number of rounds fired, the probable error is estimated to be about six per cent. If greater accuracy of these measurements is desired, it could be obtained by repeating the experiments on a calm day.

From the results given in Table III, which are based on the assumption that the rifle is supported at the middle of the butt (an assumption that probably does not hold exactly), it may be seen that the compensations accomplished by both the Cutts Compensator and the Browning Flash Hider is only about 70 per cent complete and that therefore to accomplish perfect compensation, the design of both should be changed.*

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*It is suggested that it would be desirable to conduct experiments with an automatic rifle in which the center of the butt coincides with the prolongation of the axis of the bore. With such an arrangement, there would be no occasion for compensation. Of course, if this change in the design of the butt were made, it would be necessary to use some sort of elevated sight on the automatic rifle to permit the aiming of the piece.

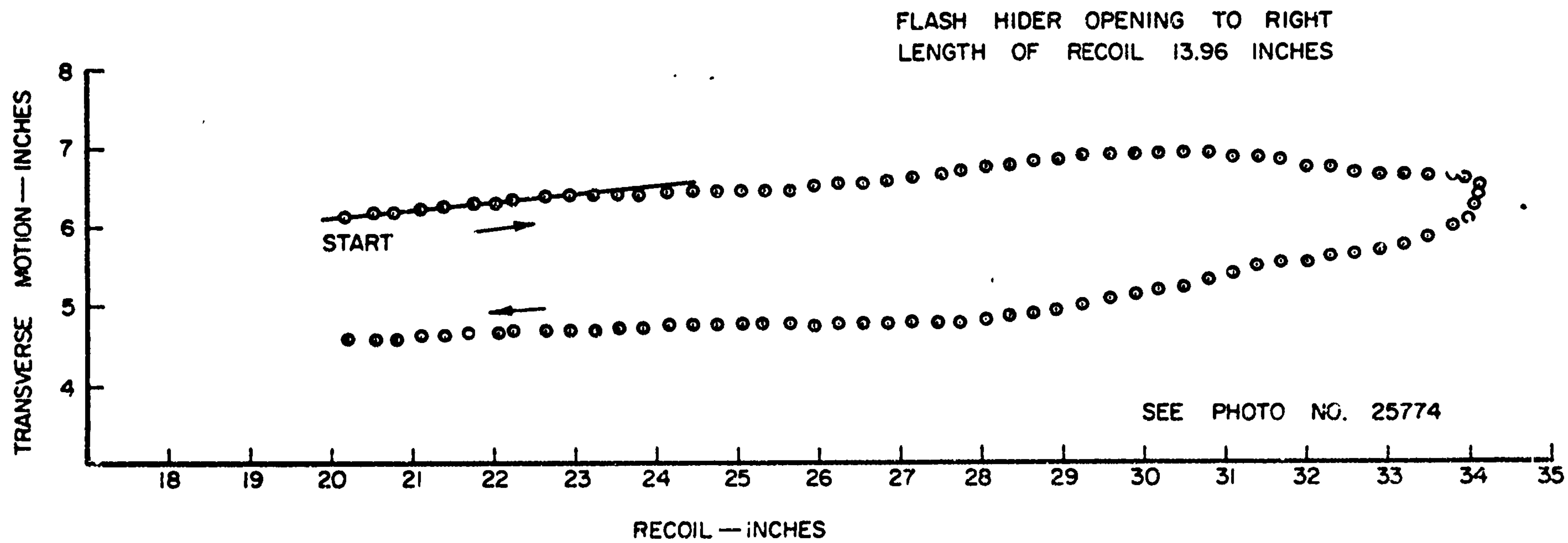

Figure — Plot of Trace of Breech Stylus.
Round No. 1.

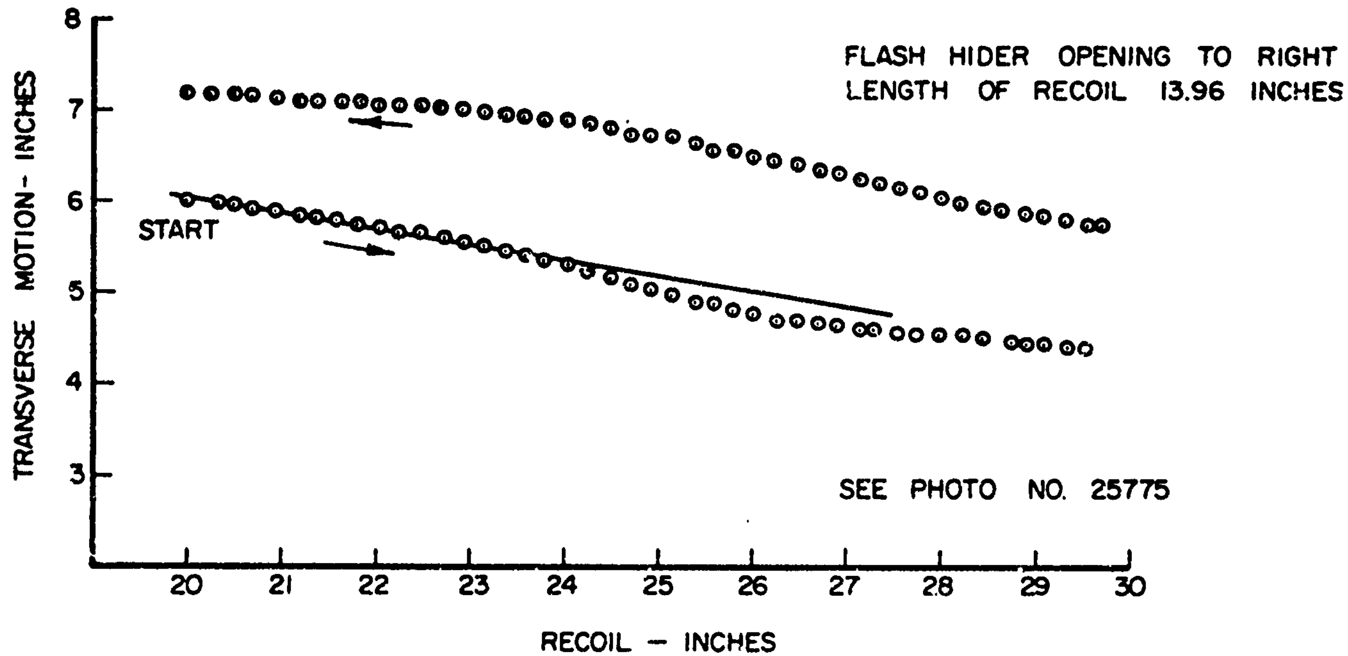

Figure —Plot of Trace of Muzzle Stylus.
Round No. 1.

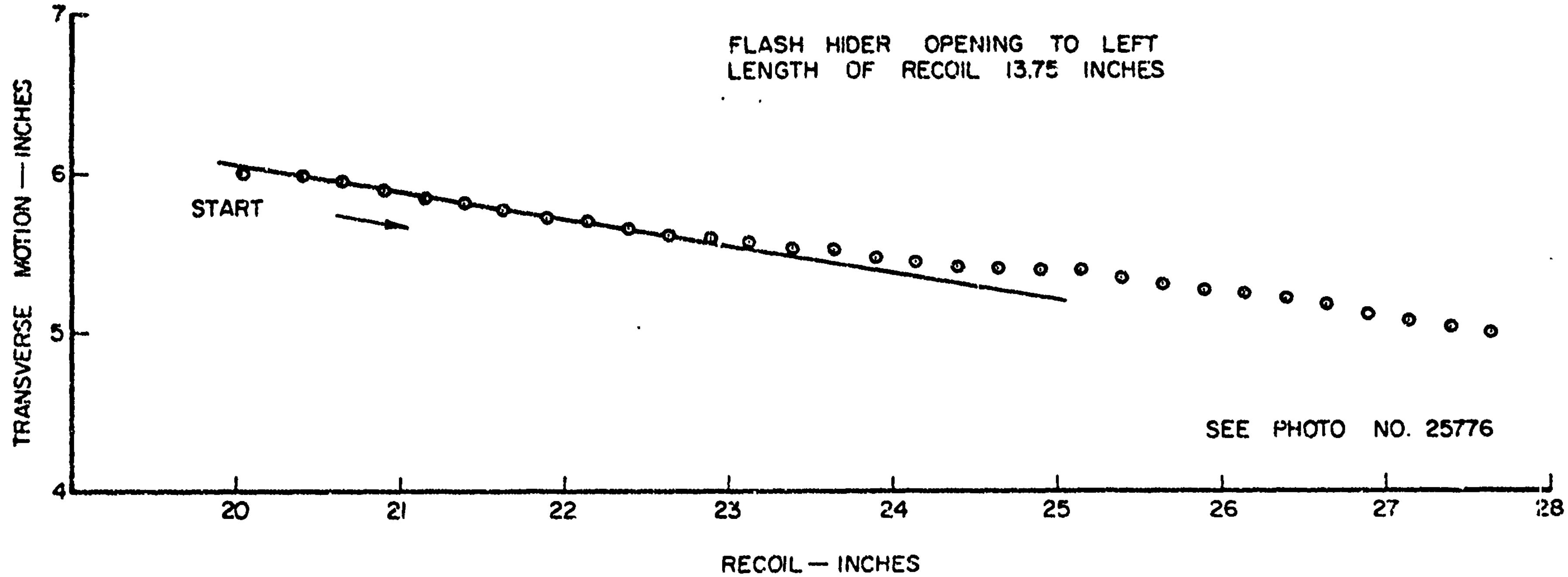

Figure — Plot of Trace of Breech Stylus.
Round No. 2.

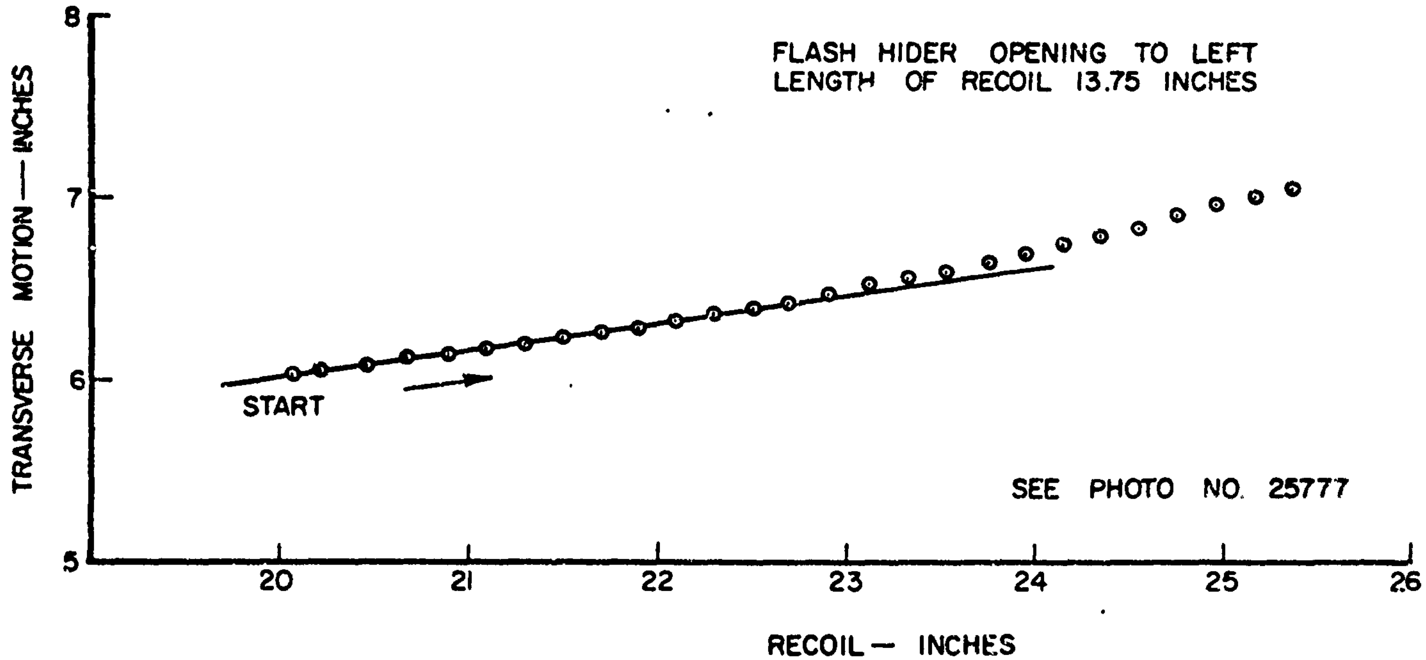

Figure — Plot of Trace of Muzzle Stylus.
Round No. 2.

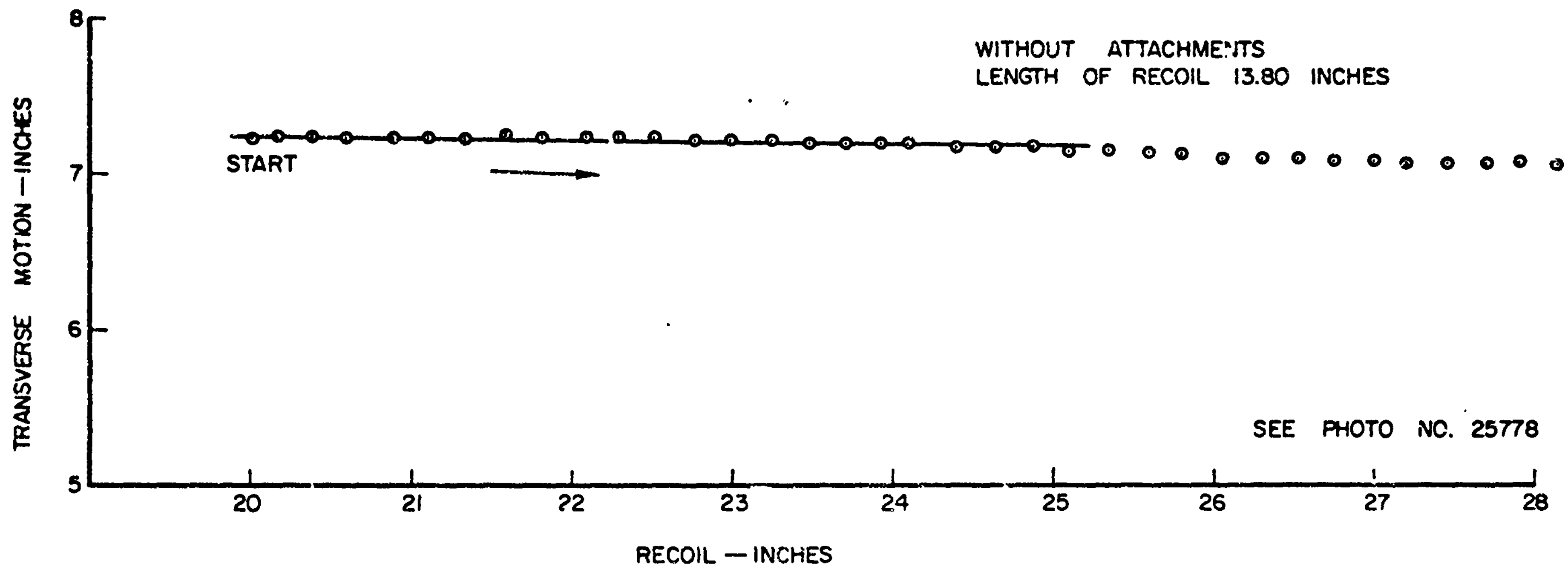

Figure — Plot of Trace of Breech Stylus.
Round No. 3.

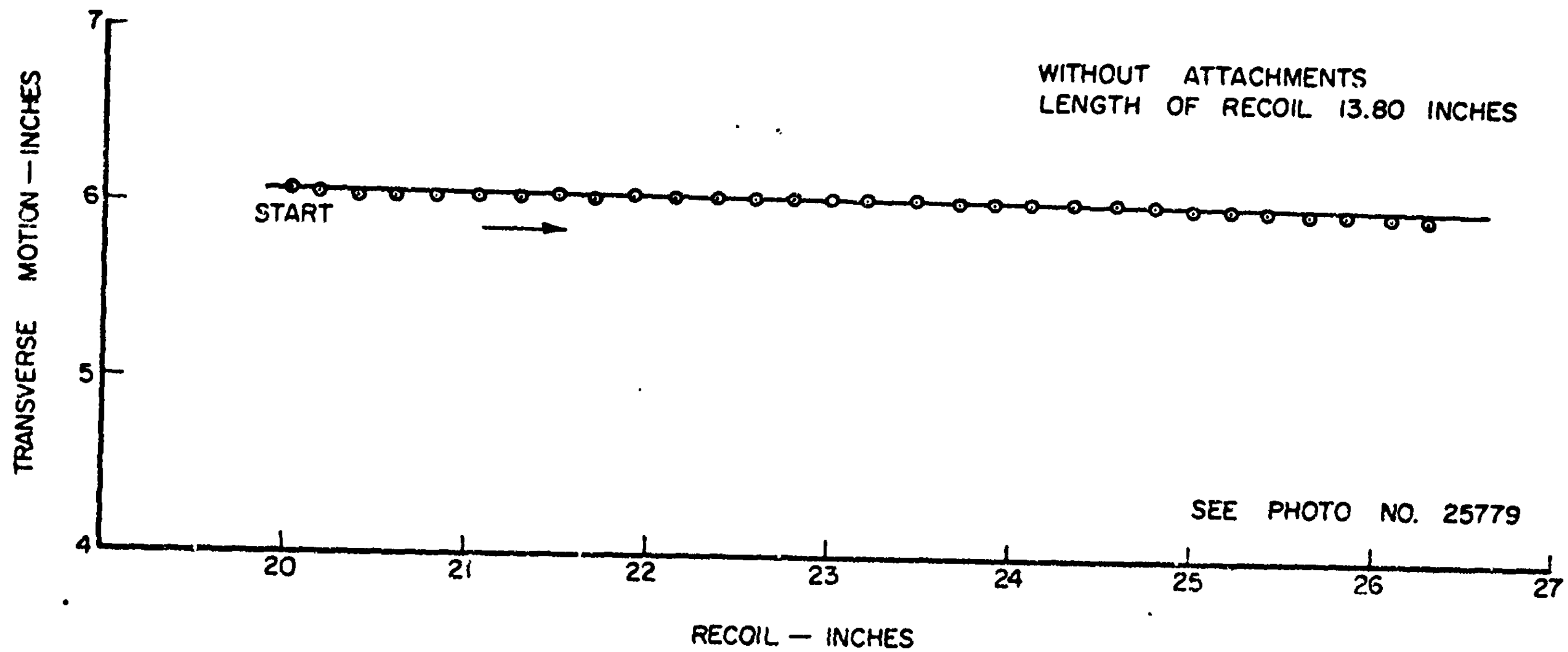

Figure — Plot of Trace of Muzzle Stylus.
Round No. 3.

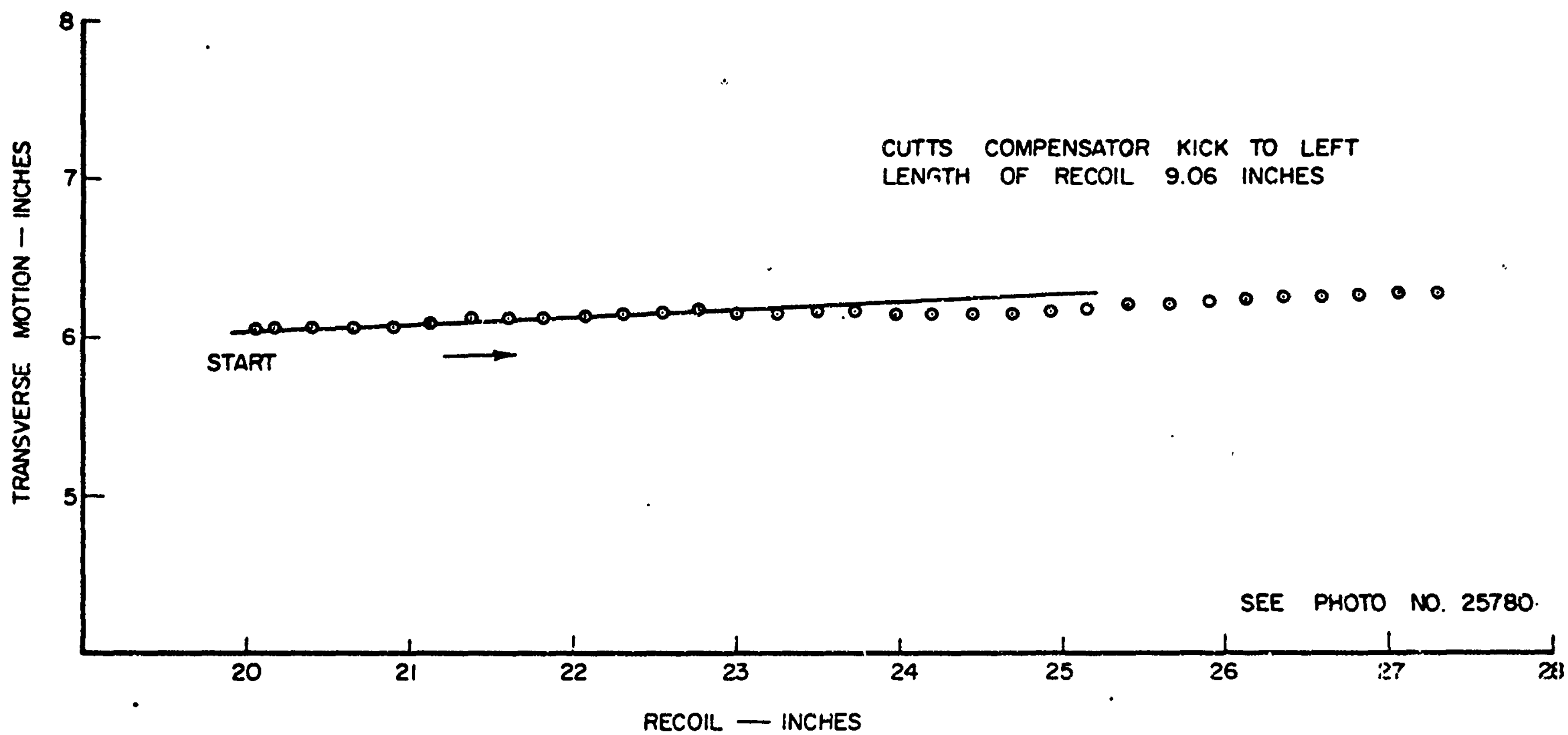

Figure —Plot of Trace of Breech Stylus.
Round No. 4.

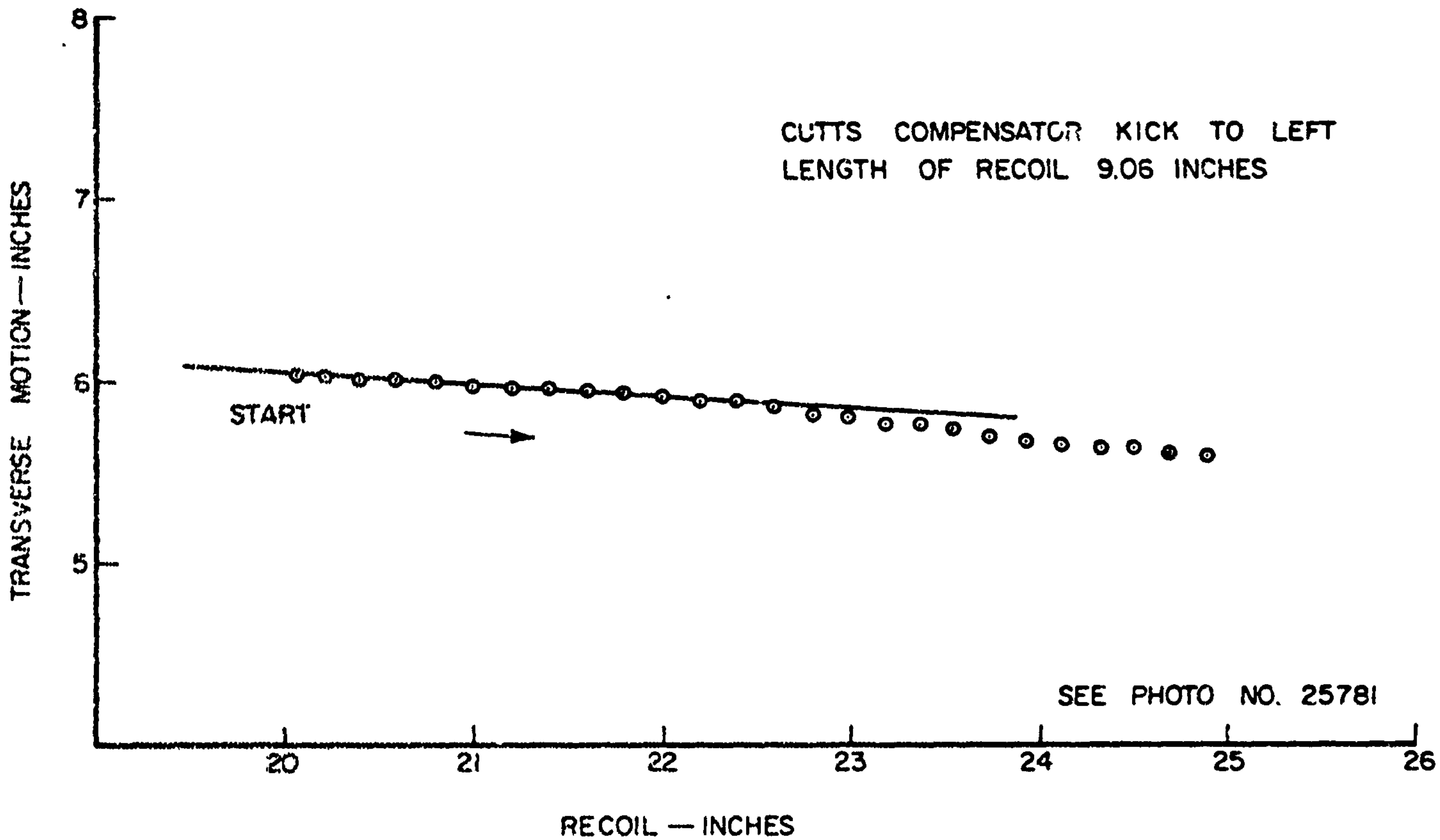

Figure —Plot of Trace of Muzzle Stylus.
Round No. 4.

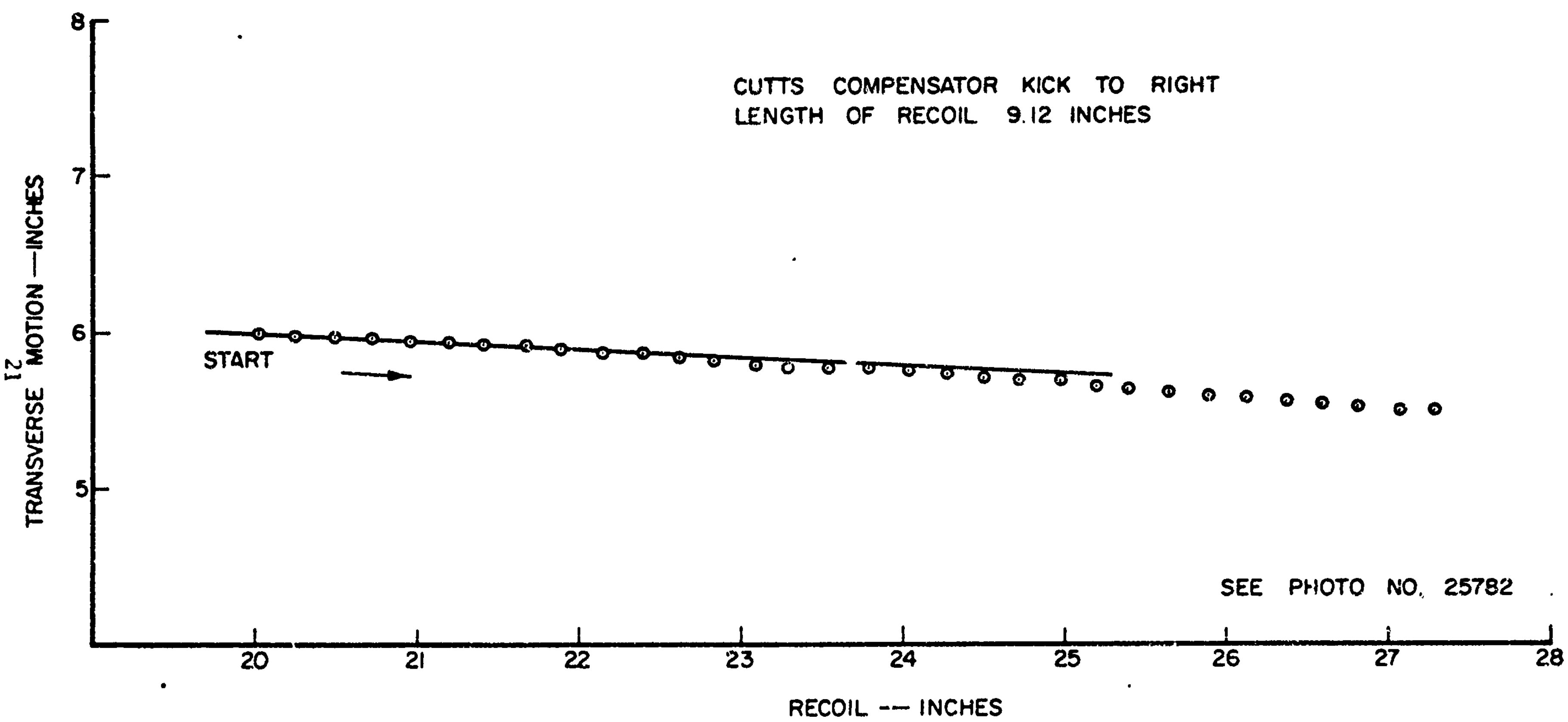

Figure —-Plot of Trace of Breech Stylus.
Round No 5.

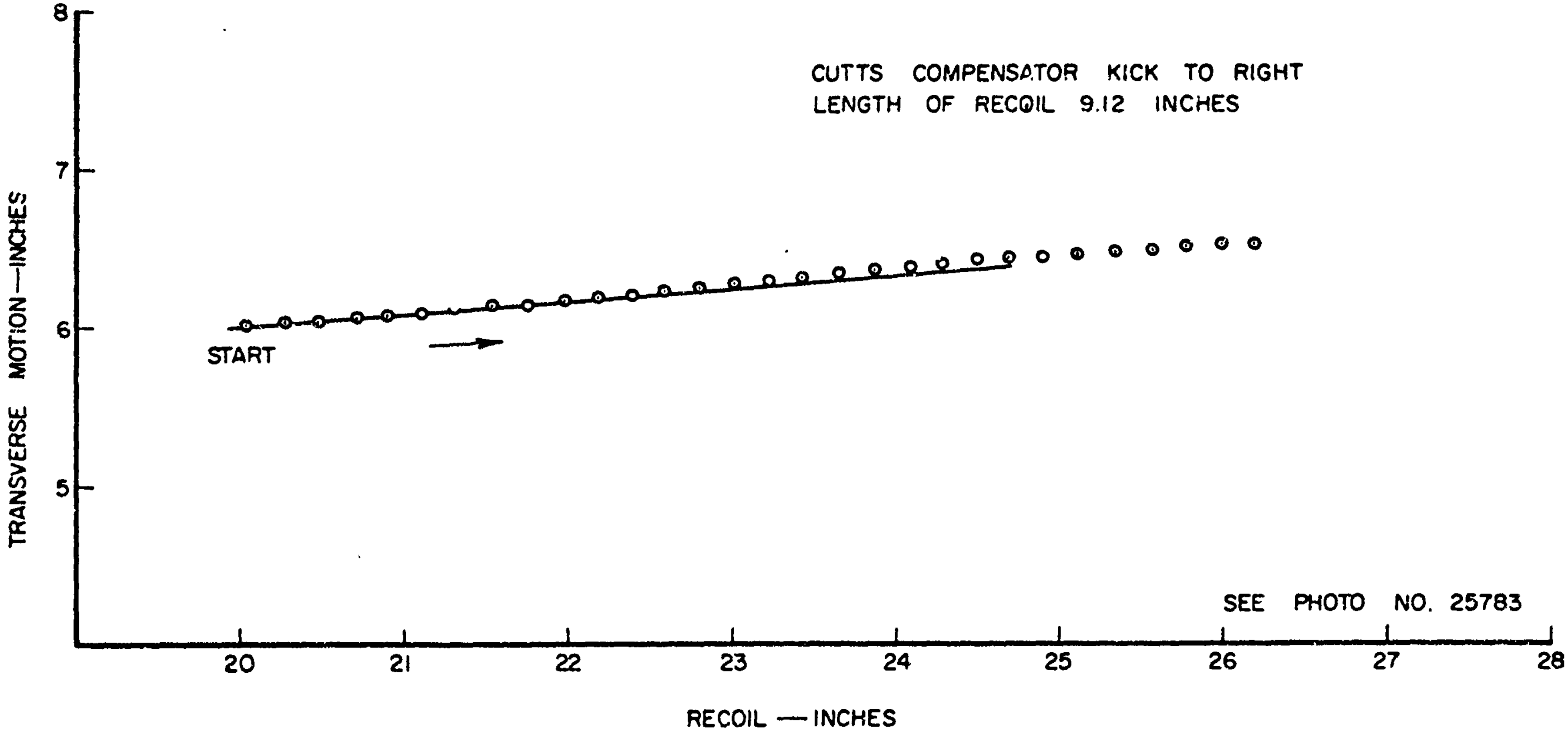

Figure —Plot of Trace of Muzzle Stylus.
Round No. 5.